

Optimal Neutron Source & Beam Shaping Assembly For Boron Neutron Capture Therapy

NEER Project
DE-FG07-98ID13642
Topical Report for
July 1999 – June 2000

By

Jasmina Vujic and Ehud Greenspan
Department of Nuclear Engineering
University of California
Berkeley, CA 94720
Vujic@nuc.berkeley.edu
gehud@nuc.berkeley.edu

The primary objective of the second year of this NEER project was identification of the maximum attainable beam quality for Boron Neutron Capture Therapy (BNCT) using the two-dimensional SWAN optimization code we developed during the first year. Specific objectives of the second year work were the following: (1) Establish the optimization criterion to be used for the 2-D BNCT Beam Shaping Assembly (BSA) optimization. (2) Benchmarking of the 2-D SWAN. (3) Optimization of the BSA for selected neutron sources, and (4) Study of the sensitivity of the attainable treatment beam characteristics and of the optimal BSA design to tumor location and boron concentration (including compound factors etc.).

Benchmarking

A significant effort was devoted to the benchmarking of the 2-D SWAN. A description of part of the benchmarking work can be found in Ref. 1. In the following we shall describe an additional benchmark: comparison of the 2-D versus 1-D SWAN for a spherical assembly with a central neutron source. The right side of Figure 1 illustrates how we modeled the sphere for the 2-D analysis; the actual step changes in R and Z were pretty small – on the order of 1cm for an average sphere radius of 35 cm. The BSA constituents are taken to be MgF_2 , Pb and ^6LiF . The neutron source is $^7\text{Li}(2.5\text{MeV p, n})$ -- that obtained when 2.5MeV protons impinge on a ^7Li target; it is located at the central 0.5cm zone of the sphere. The boron concentration, RBE, compound factors, tumor location etc. are defined in Ref. 1.

Figure 2 compares the dose-equivalent profile across the brain corresponding to the two optimal BSA. The agreement is good.

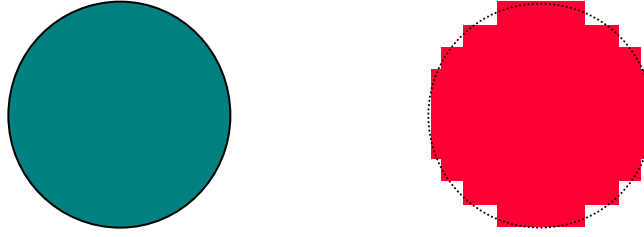


Figure 1 A cut through a 35cm radius spherical BSA used for benchmarking the 2-D (right) versus the 1-D (left) SWAN.

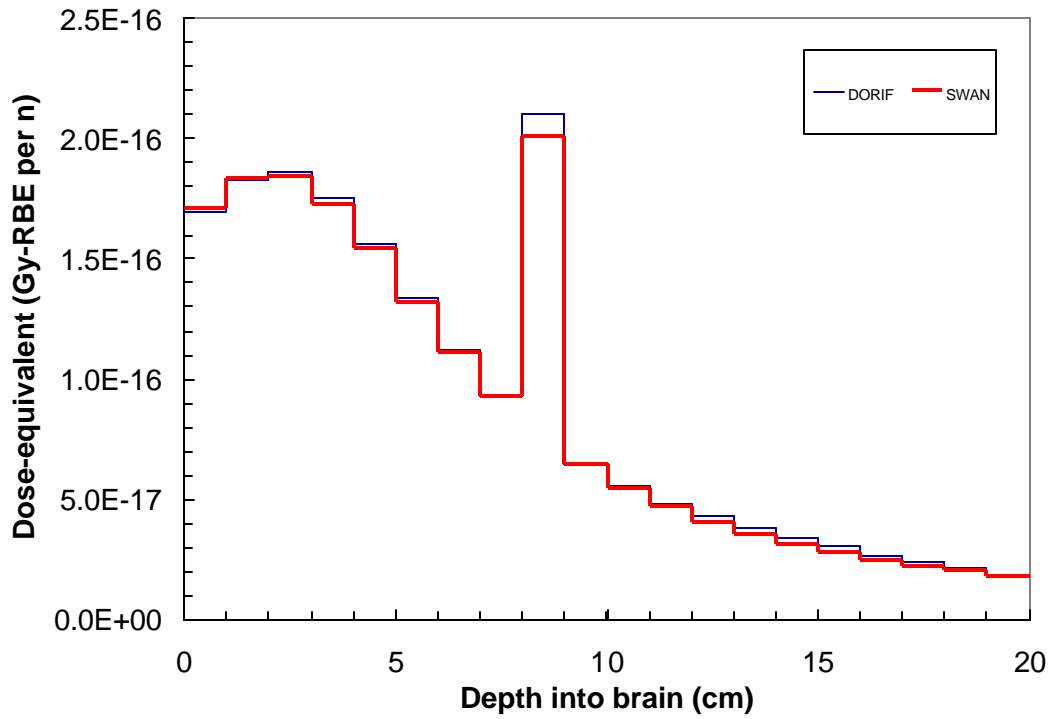


Figure 2 Comparison of the dose-equivalent profile from optimal BSA designed with the 2-D SWAN (also called “DORIF”) and with the 1-D SWAN (“SWAN”)

Optimization Criterion

The ideal optimization criterion is maximizing H/L_{\max} while constraining L_1 to $\sim 0.9L_{\max}$. In the above H is the maximum equivalent dose delivered to the tumor per source neutron, L_1 is the equivalent dose delivered per source neutron to the normal tissue at the first interval in the brain

(“skin”), and L_{\max} is the maximum equivalent dose delivered per source neutron to the normal tissue. At present SWAN can not apply a constraint. Hence, a couple of alternate optimization criteria were tried: (1) Maximizing H/L_{\max} , and (2) Maximizing H/L_1 . It was found that when using the H/L_{\max} criterion, L_1 can become as large as L_{\max} . On the other hand, when maximizing H/L_1 , L_{\max} usually comes out to be larger than L_1 . Hence we adopted the H/L_1 maximization as the optimization criterion. This criterion is also more convenient to use than H/L_{\max} , as the location of L_1 is fixed, whereas that of L_{\max} can (and does) vary with the optimization.

BSA Optimization

A major effort this year was devoted to the 2-D optimization of the design of beam shaping assemblies for a number of different neutron sources. The optimization were aimed at maximizing H/L_1 where H is located between 8 and 8.5 cm inside the brain (deep-seated tumor; the most difficult to treat). Other assumptions concerning boron concentrations, RBE and “compound factors” are the same as reported on in Ref. 1. We shall give more details about the optimization problem setup by illustrating the outcome of one system optimization.

The three figures in the Appendix show optimal “composition maps” arrived at by the 2-D SWAN for a soft spectrum ${}^7\text{Li}(2.5\text{MeV p, n})$ neutron source. Shown in these figures is a R-Z cut of the system analyzed. The BSA is 35 cm thick (extending from 50 cm to 85 cm in the Z direction) and 60 cm in radius (including the radial reflector). Above the BSA there is a 10 cm thick collimator that has a 20 cm wide opening (10 cm in radius). The brain is located just above the collimator opening. The neutron source is located in a 5 cm radius, 5 cm high cavity at the central bottom of the BSA. A Pb reflector, 50 cm in thickness, is located on the other side of the BSA. The grid shown in the figures denotes the boundaries of the zones the BSA is divided into; each zone is of a uniform composition. The volume fraction of the zone constituents may vary from zone to zone. Three constituents are considered in this study: MgF_2 , Pb and ${}^6\text{LiF}$. The collimator consists of 75% (volumetric) of polyethylene (fixed); the remainder 25% are to be shared by Pb and by ${}^6\text{LiF}$ (variable concentration). The numbers in each rectangle denotes the 2-D SWAN determined volume fraction of the constituent under consideration in that specific zone. It is found (see Appendix) that, in the optimal BSA, MgF_2 is to occupy most of the volume fraction. ${}^6\text{LiF}$ is called for primarily at the 10 cm thick shell around the collimator opening as well as at the last 2 cm of the BSA below the collimator opening. A small amount of ${}^6\text{LiF}$ is also to be mixed with the MgF_2 throughout most of the BSA. Pb is called for, primarily, in the radial reflector and in the collimator.

Figure 3 shows the optimal neutron spectrum in the last axial and innermost radial interval before the brain for 2 BSA: one is the 35cm thick (35cm from the bottom of the source) described above, and the other is for a similar, but thicker BSA - 45 cm from the bottom of the source. The shape of the spectra is similar; they both peak at the keV energy range. But the 45cm BSA spectrum peak is somewhat narrower. This leads to a higher H/L_1 value, as illustrated in Figure 4. Also seen from Fig. 4 is that it takes many iterations of the 2-D SWAN to converge to

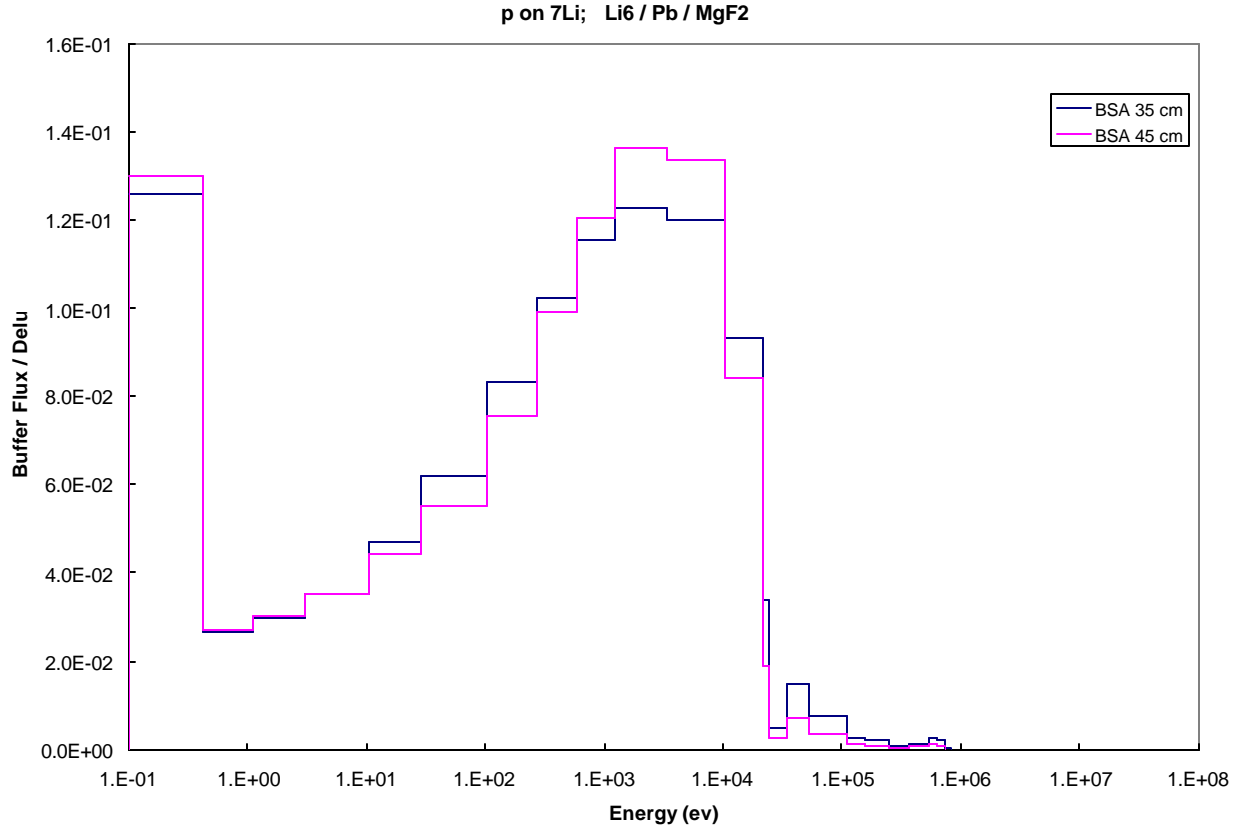


Figure 3 Effect of BSA thickness on the optimal neutron spectrum calculated with 2-D SWAN

the maximum H/L_1 . Figure 5 shows the dose-equivalent distribution across the brain for the two BSA thicknesses discussed above. It is observed that L_1 is, indeed, smaller than L_{\max} , as wished. It also shows that the value of H decreases as the BSA thickness increases. By generating the maximum H/L_1 (and the corresponding H/L_{\max}) and H values for different BSA thicknesses for different neutron sources, we'll be able to compare the relative attractiveness of the different sources.

Sensitivity study

It turns out that the computer time required for solving a 2-D transport problem at the accuracy required for accurate optimization is very long. Consequently we did not manage to get yet to the sensitivity study.

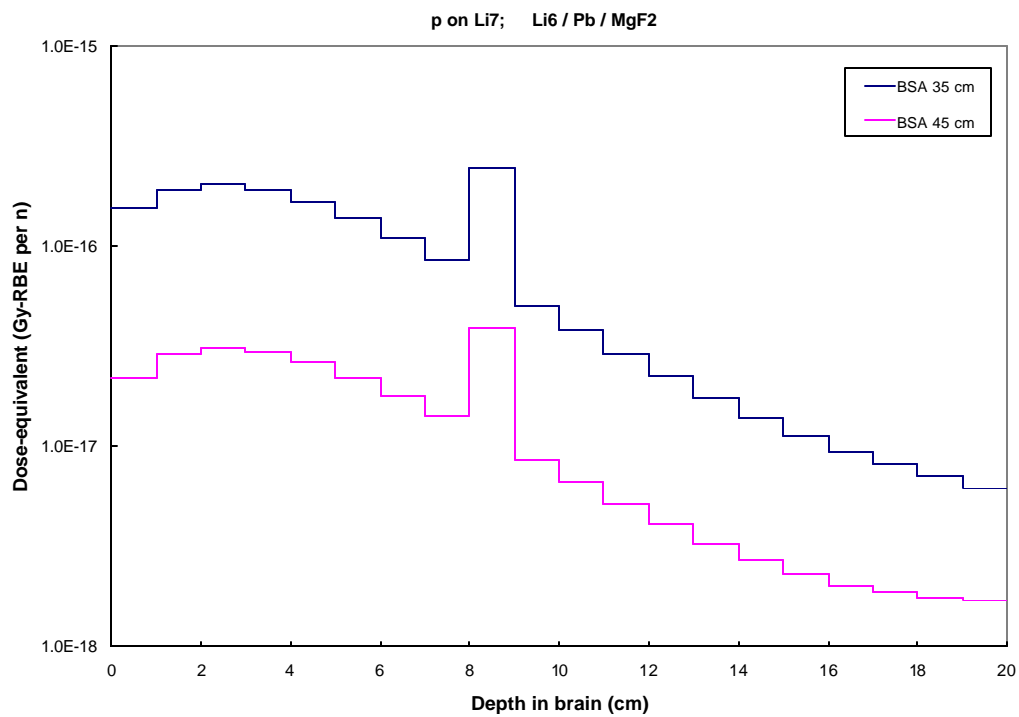


Figure 4 Dose-equivalent across brain center-line from 2-D SWAN optimized BSA

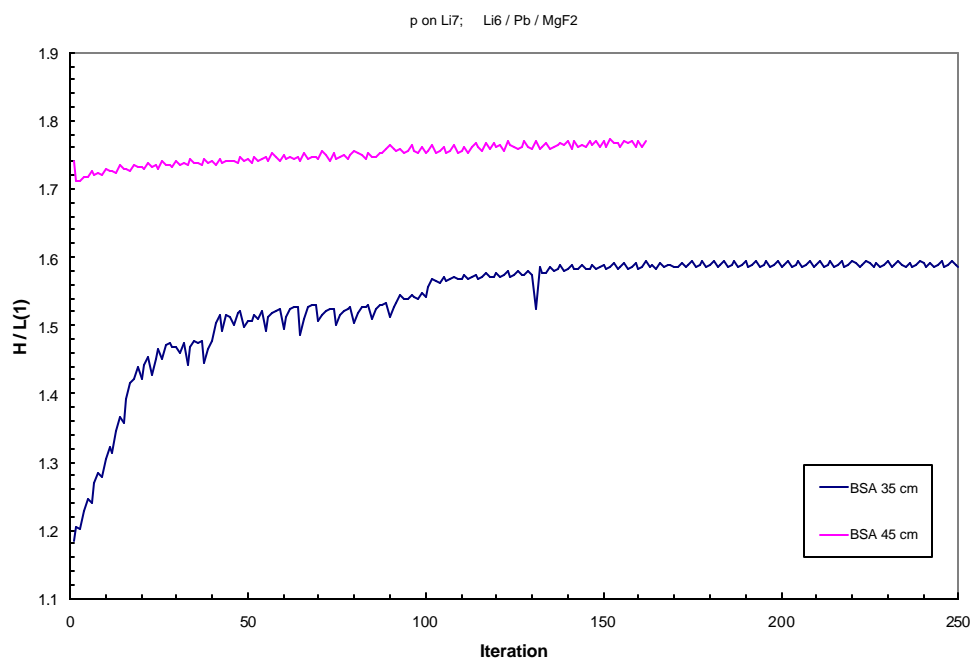


Figure 5 H/L_1 evolution in the 2-D SWAN iterative optimization process.

Summary

The 2-D SWAN (also called “DORIF”) we developed under this NEER sponsored project is found to be able to accurately identify the optimal composition of two-dimensional systems. In order to provide accurate results, the overall time it takes to find the optimal design can be uncomfortably long. In the future we’ll try to improve the optimization iteration algorithm so as to shorten the overall optimization process.

Optimal BSA designs were identified with the new 2-D SWAN for the softest spectrum [$^7\text{Li}(2.5\text{MeV p, n})$] and the hardest spectrum (D-T) neutron sources being considered for BNCT applications. The performance of the 2-D optimal systems is found to be better than the performance we previously obtained from 1-D optimization of simplified BSA. In the near future we expect to be able to rank the relative attractiveness of different neutron sources for BNCT applications based on the new 2-D optimization studies.

References

1. Y. Karni, D. Regev, E. Greenspan and J. Vujic, “Two Dimensional Nuclear Optimization Capability,” Paper ICONE-8750 in the Proc. 8th Int. Conf. On Nuclear Engineering, Baltimore, MD, April 2-6, 2000.

APPENDIX

2-D SWAN Optimized Composition of 35cm Thick BSA for $^7\text{Li}(2.5\text{MeV p, n})$ Source

115	T I S S U E		V A C U U M									
95	A I R G A P		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
94			0.030	0.051	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
93			~0	0.025	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
92			0.019	0.118	0.241	0.25	0.25	0.25	0.25	0.25	0.25	0.25
91			~0	0.208	0.214	0.229	0.25	0.25	0.25	0.25	0.25	0.25
H 88			0	0.025	0.159	0.164	0.199	0.245	0.25	0.25	0.25	0.25
E 85	0	0.051	0.063	0.028	0.977	0.980	0.991	0.991	1	1	1	1
I 84	0.150	0.003	0.025	0.001								
G 83	0	0	0.024	0								
82	0	0	0.009	0								
H 80	0	0	0	0	0	0.879	0.850	1	1	1	1	1
79	0	0	0	0								
T 76	0	0	0	0								
(73	0	0	0	0								
C 70	0	0	0	0	0.321	0.501	0.725	0.751	1	1	1	~1
M 67	0	0	0	0								
64	0	0	0	0								
61	0	0	0	0								
60	0	0	0	0	0.471	0.501	0.721	0.780	0.999	0.999	0.999	0.999
58	0	0	0	0.003								
55	VACUUM + SOURCE	0	0	0.008								
52	~0	0	0									
50	P B - R E F L E C T O R											
0	R A D I U S (C M)											

115	T I S S U E		V A C U U M									
95	A I R G A P		0	0	0	0	0	0	0	0	0	0
94			0.220	0.199	0	0	0	0	0	0	0	0
93			~0.25	0.225	0	0	0	0	0	0	0	0
92			0.231	0.132	0.009	0	0	0	0	0	0	0
91			~0.25	0.042	0.036	0.021	0	0	0	0	0	0
H 88			0.25	0.225	0.091	0.086	0.051	0.005	0	0	0	0
E 85	0.038	0.016	0.937	0.550	0.011	0.010	0.009	0.008	0	0	0	0
I 84	0.012	0.008	0.605	0.330								
G 83	0.453	0.054	0.504	0.100								
82	0.015	0.001	0.073	0.002								
H 80	0.009	0.007	0.009	0.015	0.015	0.005	0	0	0	0	0	0
T 76	0.006	0.015	~0	0.026								
(73	0.005	0.013	0.001	0.017								
C 70	0.006	0.011	0.003	0.010								
M 67	0.009	0.008	0.003	0.007	0.010	0.002	0	0	0	0	0	0
64	0.010	0.006	0.003	0.005								
61	0.005	0.004	0.002	0.003								
60	0.005	0.004	0.002	0.003	0.008	0.001	0.001	0	0	0	0	0
58	0.002	0.001	0.001	0.003								
55	VACUUM + SOURCE	0	0.002	0.003								
52	~0	0.004	0.004									
50	P B - R E F L E C T O R											
0	R A D I U S (C M)											